ARMD Strategic Thrust 4: Transition to Low-Carbon Propulsion

Barb Esker, Rich Wahls, and Roadmap Teams 4A & 4B

Aeronautics R&T Roundtable, Washington DC

May 24, 2016

Thrust 4

Transition to Low-Carbon Propulsion

- Characterize drop-in alternative fuels and pioneer low-carbon propulsion technology

Thrust 4a – Alternative Fuel Roadmap Team

Kick-off 7/23/15

Scope: Drop-in fuels & associated architectures
Vertical lift/fixed wing, civil missions; dual-use military

Co-leads: **Barb Esker** / Rich Wahls
AFRC: Steve Jensen
GRC / AATT / TTT: Angela Surgenor
LaRC: Bruce Anderson
ARMD: Dell Ricks

GRC, Systems, Propulsion: Chris Snyder
LaRC, Systems, Propulsion: Mark Guynn
AAVP: Peggy Cornell

Thrust 4B – Hybrid Electric Roadmap Team

Kick-off 6/12/15

Scope: Large Transport, Small Thin-haul, passenger vertical lift, unmanned aerial vehicles
[internal community—AATT, CAS (DELIVER, SCEPTOR)]

Co-leads: **Kevin Carmichael** / Rich Wahls
AATT: Amy Jankowsky
CAS/DELIVER: Lee Kohlman
CAS/SCEPTOR: Mark Moore
ARMD: Dell Ricks

AFRC: Hyun Dae Kim
ARC: Nateri Madavan
GRC: Jim Felder
LaRC: Dan Williams
TTT: Jeff Viken

Outline

- Background
- Vision
- Introduction
- Strategy
- Outcomes, Benefits, Capabilities
- Research Themes
- Roadmaps
- Stakeholder roles, partnerships
- Top 5 Risks / Dependencies
- Additional materials

NASA Aeronautics Six Strategic Thrusts

NASA has identified Six Strategic Thrusts to focus research in response to Three Aviation Mega-Drivers. Thrust 4 – technology convergence to impact environmental challenges

T1 — **Safe, Efficient Growth in Global Operations**
- Enable full NextGen and develop technologies to substantially
- reduce aircraft safety risks

T2 — **Innovation in Commercial Supersonic Aircraft**
- Achieve a low-boom standard

T3A ST
T3B VL — **Ultra-Efficient Commercial Vehicles**
- Pioneer technologies for big leaps in efficiency and environmental performance

T4 — **Transition to Low-Carbon Propulsion**
- Characterize drop-in alternative fuels and pioneer
- low-carbon propulsion technology

T5 — **Real-Time System-Wide Safety Assurance**
- Develop an integrated prototype of a real-time safety monitoring and assurance system

T6 — **Assured Autonomy for Aviation Transformation**
- Develop high impact aviation autonomy applications

Thrust Relationships

Vehicle-centric look & some vehicle-dependent context

The six Thrusts are not independent. Dependencies exist between all thrusts. Low-carbon propulsion exists to be applied to vehicles, has direct implications to infrastructure and leverages/relies on advances in non-aerospace sectors.

CONVERGENT TECHNOLOGY OPPORTUNITIES

- Low-Carbon Propulsion
- Real-Time System-Wide Safety
- Autonomy

Value Proposition of Air Transportation

What I Fly

Vehicles

MISSION CAPABILITY

Combination of:
Payload, Range, Speed, Field-Length, Hover, Endurance

Environmentally Friendly, (e.g. Noise, Emissions)
Safety, Cost/Affordability

How I fly

Operations

365/24/7 OPERATIONS

Rules of the Road:
Safe, Efficient, Flexible, Resilient

Supersonic Transports
Speed 2X subsonic with minimal efficiency and environmental compatibility differences

Subsonic Transports
Backbone of air transportation, ***Environmental*** Compatibility while reducing cost, increasing range, maintaining safety

Vertical Lift
Accessibility—Field Length/ Noise/Hover with more range/speed/payload/ safety/comfort

Other Vehicle Types
e.g. small fixed wing

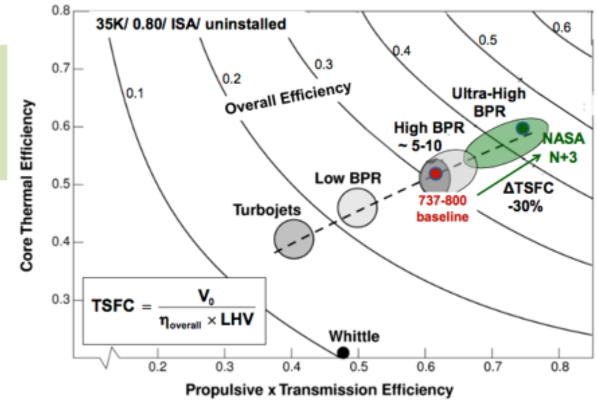
Thrust Relationships

What Distinguishes Thrust 4 from Thrust 3 (and 2) Propulsion?

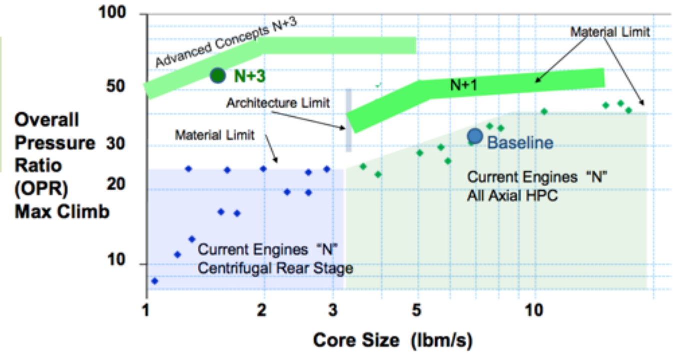
Ultra-Efficient Commercial Vehicles

Efficiency (use less energy)
Emissions (use less energy)
Noise (less perceived noise)

Airframe
Propulsion – Advanced Gas Turbines and Propulsors
Vehicle System Integration



Lord, et. al., AIAA SciTech15, AIAA-2015-0071



adv gas turbine
Small Core
fuel flexibility
hybrid systems

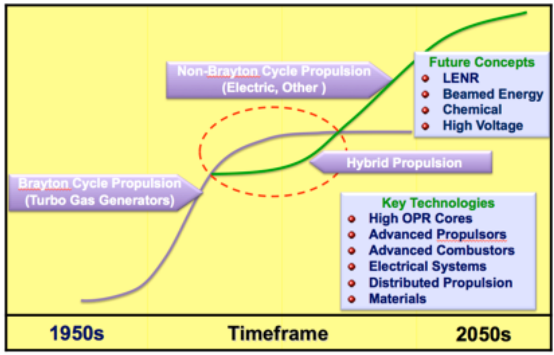
Transition to Low-Carbon Propulsion

Aviation Alternative Fuels (Drop-In)

Reduce specific carbon (use cleaner energy)
Clean, compact combustion
Gas turbines needed for foreseeable future

Alternative Energy/Power Architectures

Energy sector convergent technology*
Promise of cleaner energy
Potential for vehicle system efficiency gains (use less energy)
Leverage advances in other transportation sectors
Address aviation-unique challenges (e.g. weight, altitude)
Recognize potential for early learning and impact on small aircraft



*energy sector includes other government agencies, industry, and academia

Thrust 4 Roadmap Development

Two focused teams will result in one roadmap

Introduction & Overview

Thrust 4A—Low Carbon Emissions achieved through use of alternative jet fuels with lower life-cycle carbon footprints

- enable use in air vehicles with advanced, highly efficient propulsion systems
- inform/support the regulatory communities on the impact of the use of these fuels

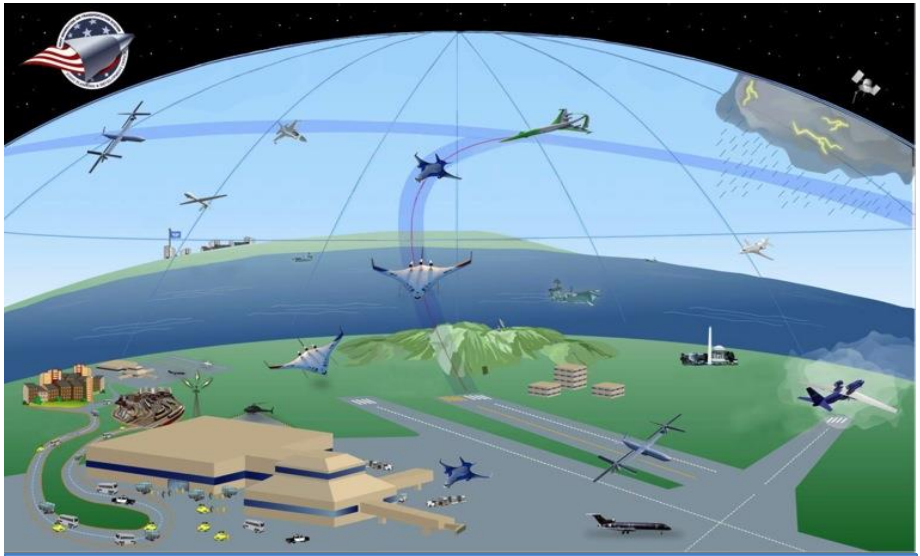
- **Vision**: To reduce the carbon footprint of air transportation through effective use of lower life-cycle carbon alternative jet fuels with known impact on the environment.

Thrust 4B—Low Carbon Emissions achieved through use of alternative propulsion systems such as electric/hybrid electric propulsion

- **Vision**: To explore, advance and transform aviation via electric/hybrid electric propulsion integrated with airframes to increase aircraft functionality, reducing carbon emissions while improving operational efficiency and reducing noise

A Vision for the Future of Civil Aviation

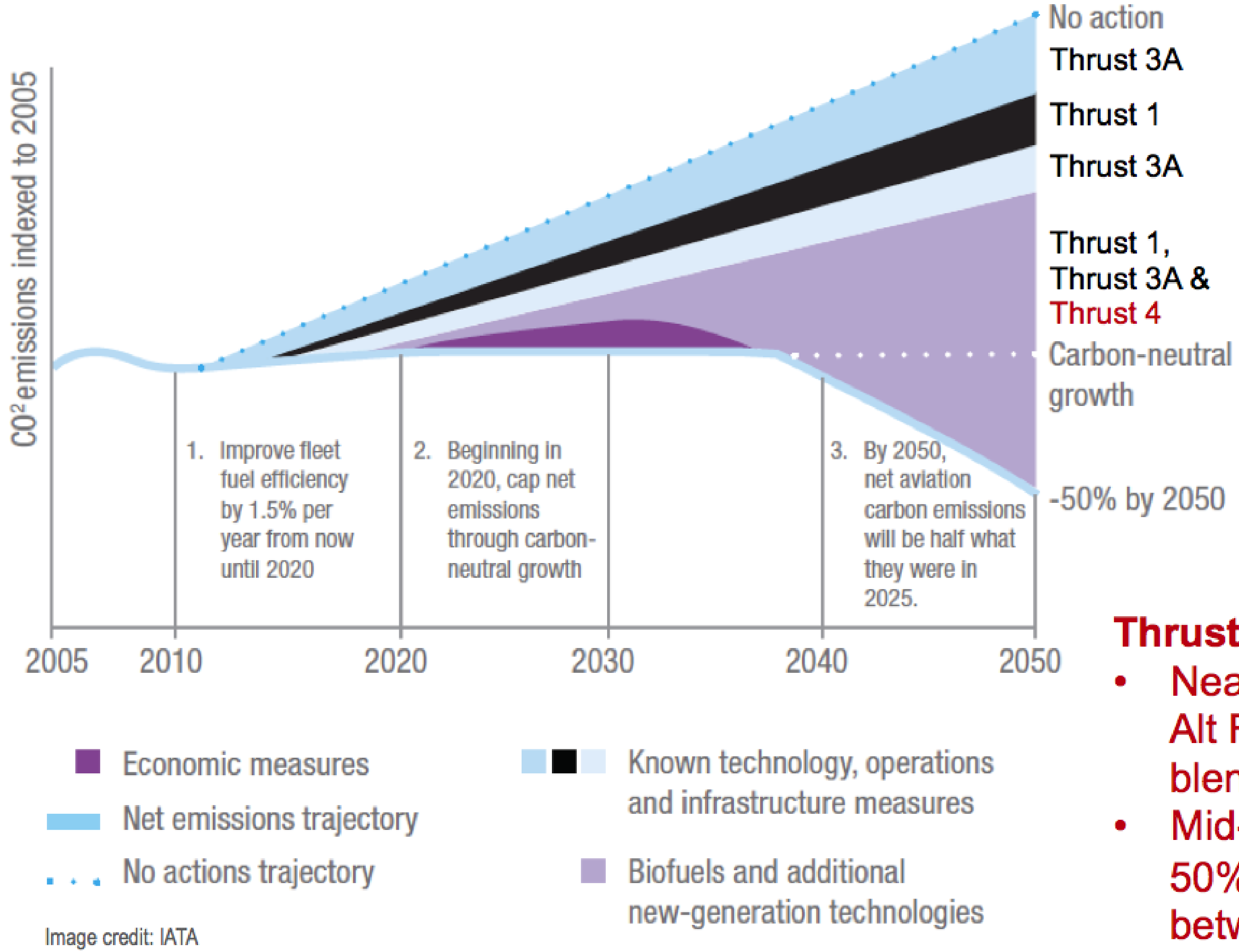
- There will be a radical increase in new and cost-effective uses of aviation
- The skies will accommodate thousands of times the number of vehicles flying today
- Travelers will have the flexibility to fly when and where they want in a fraction of the time that it takes today
- All forms of air travel will be as safe as commercial air transport is today
- Subsonic transports will remain the backbone of long-haul global and domestic travel
- Significantly reduced carbon and noise footprints from aviation



- Low-carbon propulsion will be designed into vehicles of all sizes and missions
- Low-carbon propulsion will have its largest impact on aviation’s carbon footprint via subsonic transports
- Low-carbon propulsion will enable new vehicles that create economic benefit for unique missions/services
- Alternative jet fuels will be the norm

Introduction—Major Aviation Community "Driver"

Reduce carbon footprint by 50% by 2050…



Near to mid opportunity "Industry pull"

Mid to far opportunity "NASA push"

Thrust 4

- Near-to-Mid term Drop-in Alt Fuels up to 50% blend
- Mid-to-Far term Beyond 50% blend Convergence between 4A and 4B

…. in the face of increasing demand, and while reducing development, manufacturing and operational costs of aircraft & meeting noise and LTO NOx regulations

Outcomes

Transition to Low-Carbon Propulsion

The Roadmap Team reviewed the current SIP Outcomes and are not recommending changes

Low-Carbon Propulsion will impact vehicle classes/missions, and will be realized in different forms for different vehicles over different timespans

- Aviation's carbon footprint is driven by subsonic transports (our prime motivation)
- Alternative/hybrid systems enable new/enhanced opportunities for aviation (smaller vehicles, early adopters, on the road to large vehicles
- Lower life-cycle carbon content per unit energy, and lower energy use possible

Community Outcomes (no change proposed for the updated SIP):

2015	2025	2035
Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems	Initial Introduction of Alternative Propulsion Systems	Introduction of Alternative Propulsion Systems to Aircraft of All Sizes relative to 2005

Outcomes, Benefits, Capabilities

Community

Thrust 4: Transition to Low-Carbon Propulsion Thrust 4A: Enable Use of Alternative Jet Fuel			
	2015	2025	2035
Community Outcomes	Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems	Initial Introduction of Alternative Propulsion Systems	Introduction of Alternative Propulsion Systems to Aircraft of All Sizes
Benefits	• Optimized/accelerated use of lower life-cycle carbon drop-in fuels at certified, & potentially higher, blend levels • Scientific datasets to inform decisions on standards for emissions	• Optimized use of lower life-cycle carbon fuels in advanced propulsion systems with new-generation technologies.	• Advanced propulsion system concepts available for optimized use of alternative fuels in alternative propulsion systems • Alternative fuel use is the norm
NASA Outputs/Capabilities	• Lab-scale experimental & analytical data of combustion, combustion products & combustor operability to validate physics-based tools & concepts • Combustion & combustor concepts leveraging attributes of alternative jet fuels • Quantified ground & in-flight engine emissions & contrail data including techniques & measurement methods necessary for informed decisions on standards for emissions & for contrail formation models including alternative jet fuel effects • Advanced measurement techniques for engine & combustion rig emissions	• Physics-based combustion & combustor models with verified effects of alternative jet fuels in 50-100% blends • Combustion & combustor concepts optimized for drop-in fuels in 50-100% blends • Contrail microphysics model for predicting effects of increased combustion efficiency & fuel hydrogen content	

* Research horizons used in Federal Alternative Jet Fuel Strategy: <5 years (Near-term), 5-10 years (Mid-term), >10 years (Far-term)

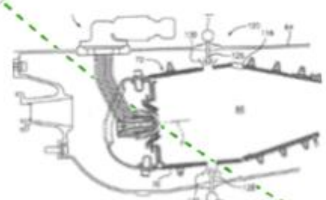
Alternative Jet Fuels

Optimize and accelerate the effective use

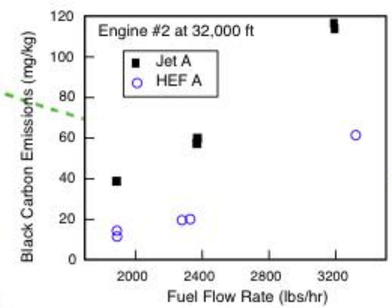
Explore and demonstrate combustor concepts that exploit future alternative fuels

Fully integrate with advanced engines

Certify, Operate



Federal Alternative Jet Fuel Strategy horizon



2040

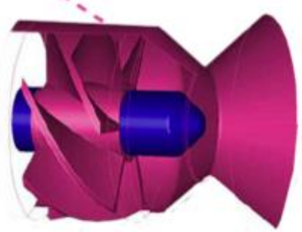
2030

Characterize the performance and emissions of an increasing spectrum of alternative jet fuels in advanced combustors

AIR

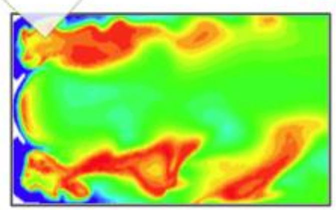
FUEL

AIR



Science to guide policy

2020



2015

Modeling & Simulation

Experimental Validation Data

Combustor/Fuel System Improvements

Explore Architecture

Advance scientific understanding relating fuels to combustion to emissions to atmospheric impact

Optimized Design & Engineering for use of LCC Fuels → +

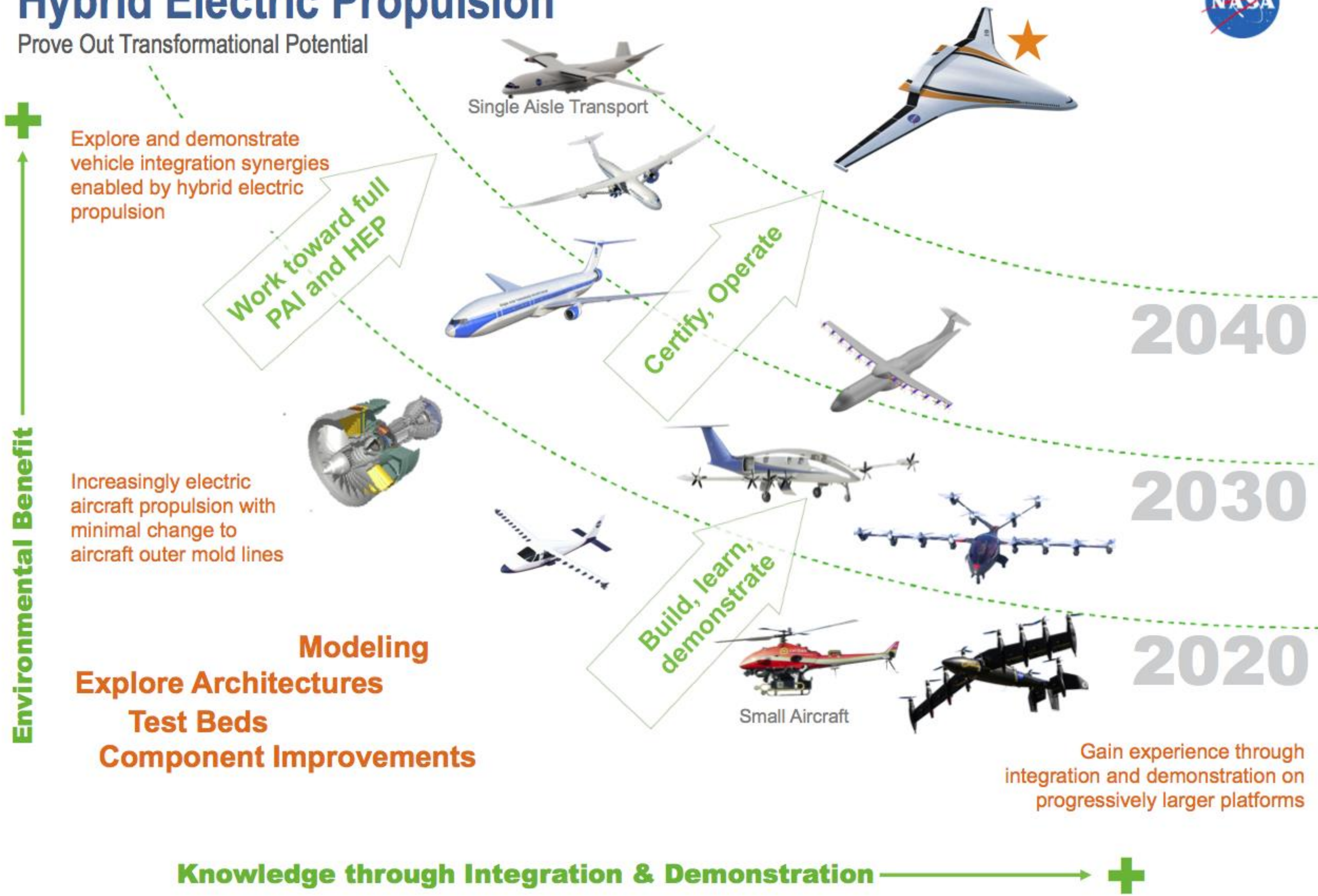
Knowledge through Basic Sciences → +

Thrust 4B: Outcomes, Products, Benefits, Capabilities

Thrust 4: Transition to Low-Carbon Propulsion Thrust 4B: Alternative Energy/Power Architectures			
	2015	2025	2035
Community Outcomes	Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems	Initial Introduction of Alternative Propulsion Systems	Introduction of Alternative Propulsion Systems to Aircraft of All Sizes
Benefits	• Established experience and knowledge base allowing for industry investment and market growth	• Certified operational aircraft in limited applications/markets • Improved fuel economy and lower carbon emissions in limited applications • Improved acoustics	• Improved fuel economy • Low carbon emissions • Lower operating costs • Enhanced safety
NASA Outputs/Capabilities	• Thin haul commuter flight demo • Small vertical lift flight demos • HEP PAI and DEP aircraft studies • High Efficiency, light weight power systems (motors, generators, energy storage, cables, etc.) • Turbofan designs with a significant part of power converted to electricity • Demonstrations of propulsion airframe integration benefit through ground and flight test • Integrated flight, electric, and turbine controls • Power and propulsion system integrated test beds • Modeling, sizing, design and analysis tools	• Regional transport flight demo • Medium size Vertical lift flight demos • Electrified propulsion air vehicle certification • Experience designing, building and operating a variety of small electric and HEP aircraft and vertical lift vehicles • An array of Government and Industry development and test facilities • Optimized architectures and supporting technology • Optimized flight operations • Advanced materials applied to HEP • High fidelity models	• Single aisle transport flight demo • Large vehicle lift flight demo • Extensive experience designing building and operating electric and HEP aircraft and vertical lift vehicles • Industry has full design and test capability • Increased & more flexible control

Hybrid Electric Propulsion

Prove Out Transformational Potential



Strategy – NASA Response to Community Drivers

Community Outcomes	2015	2025	2035
	Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems	Initial Introduction of Alternative Propulsion Systems	Introduction of Alternative Propulsion Systems to Aircraft of All Sizes

NASA Strategies

Aviation Alternative Fuels (drop-in)

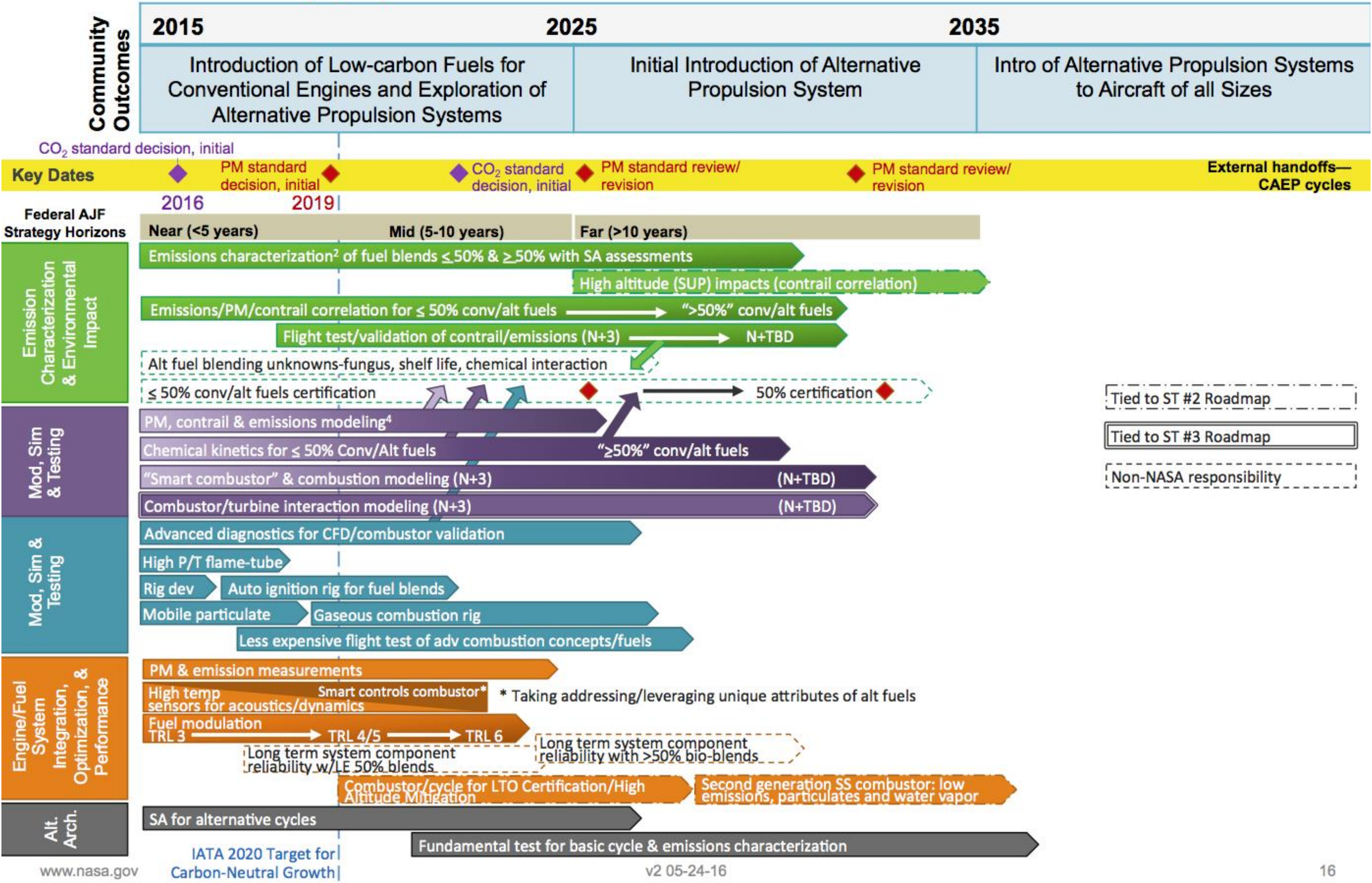
- Explore and demonstrate combustor concepts that exploit future alternative fuels
- Characterize the performance and emissions of an increasing spectrum of alternative jet fuels in advanced combustors
- Advance scientific understanding relating fuels to combustion to emissions to atmospheric impact

Alternative Energy/ Power Architectures

- Explore and demonstrate vehicle integration synergies enabled by hybrid electric propulsion
- Increasingly electric aircraft propulsion with minimal change to aircraft outer mold lines
- Gain experience through integration and demonstration on progressively larger platforms

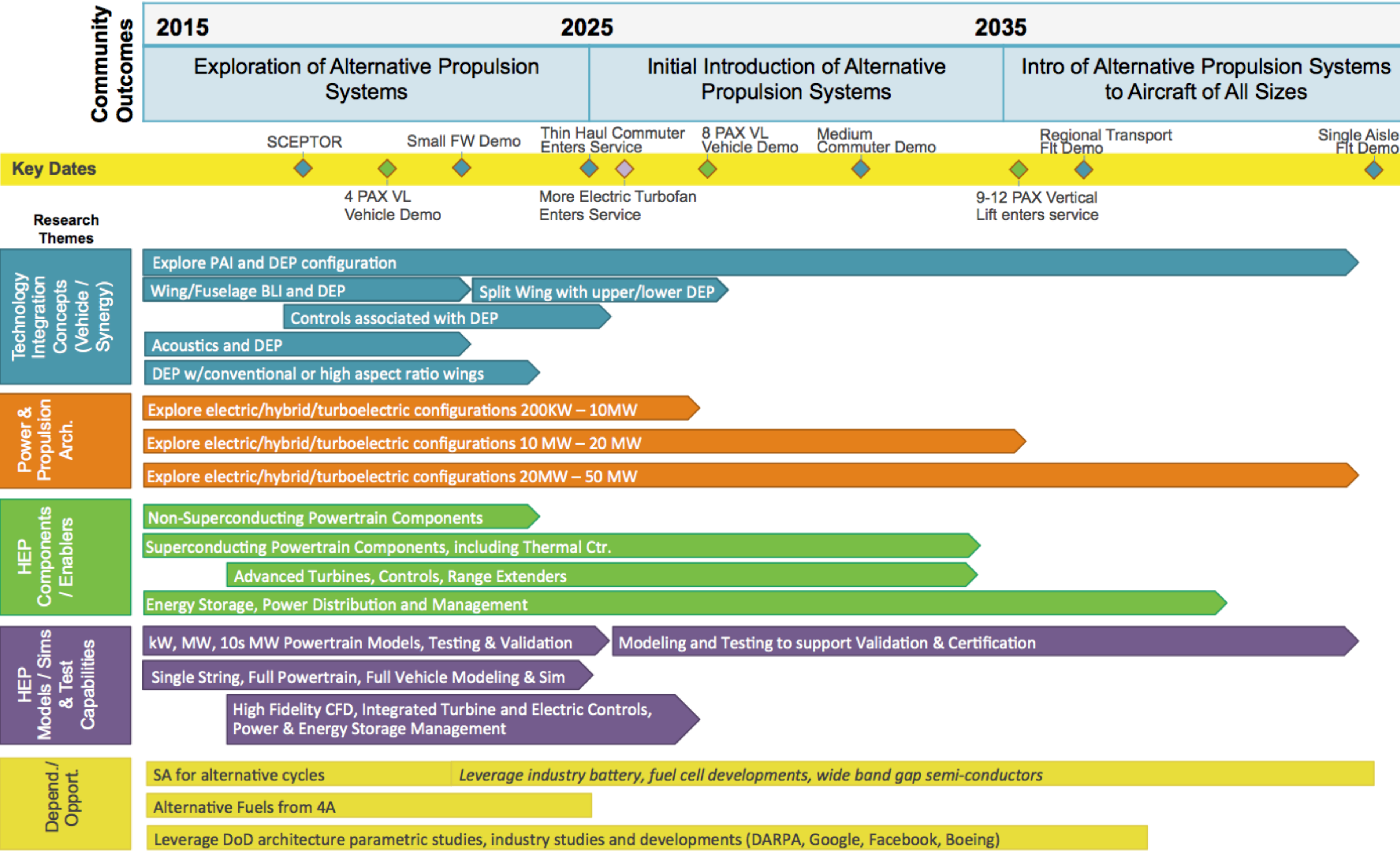
Thrust 4: Transition to Low-Carbon Propulsion

Aviation Alternative Fuels (drop-in)



Thrust 4: Transition to Low-Carbon Propulsion

Hybrid/Electric Propulsion



Integrating Thrust 4 Research Themes

Alternative Power, Propulsion, & Vehicle Architectures

Exploration of clean, quiet, & efficient transformative hybrid or alternative integrated energy, power, and propulsive systems and synergistic vehicle-level integration

Alternative Fuel Combustors & Environmental Impact

- Engine/Fuel System Integration, Optimization & Performance
- Emissions Characterization & Environmental Impact

Hybrid Electric Components & Technology

- HEP Components (e.g. motors, generators)
- HEP Technology (e.g. materials, controls)

Modeling, Simulation, Testing

R&D of innovative tools and methods (computational, experimental, & analytical) to transform power and propulsion system capability in less time with reduced uncertainty and cost

Black = Common Research Themes   Red = Alternative Fuels Research Themes   Blue = Hybrid Electric Research Themes

Research Themes (Integrated Thrust 4) DRAFT

NASA Long-term Research Areas Contributing to the Community Outcomes

- **Alternative Power, Propulsion, & Vehicle Architectures**
  - Exploration, research, and development of clean, quiet, and efficient transformative hybrid or alternative energy, power, and propulsive systems with synergistic vehicle-level integration
  - Systems Analysis to identify and quantify the high-potential, low life-cycle carbon opportunities focusing on low carbon propulsion and alternative fuels, and underlying technologies including cycles for hybrid-electric systems.
- **Alternative Fuel Combustors & Environmental Impact**
  - Emission Characterization & Environmental Impact
  - Engine/Fuel System Integration, Optimization & Performance
- **Hybrid Electric Components & Technology**
  - Research and development of integrated, flight-weight components and technologies such as increased power density electric machines, superconducting machines, advanced fuel cells, power electronics, fault protection devices and other enablers such as flight controls
- **Modeling, Simulation, and Test Capability**

PLACEHOLDER—
Work in Progress
Combine 4A/B and
simplify research
theme descriptions

Roadmap Thrust 4: Transition to Low Carbon Propulsion

Community Outcomes

2015	2025	2035
Introduction of Low-carbon Fuels for Conventional Engines and Exploration of Alternative Propulsion Systems	Initial Introduction of Alternative Propulsion Systems	Introduction of Alternative Propulsion Systems to Aircraft of All Sizes

Key Dates

Assume ~10-20 year time from TRL 4 to EIS

Ultra-Efficient Airframe

Ultra-Efficient Propulsion

Ultra-efficient Vehicle System Integration

ModSim & Test Capability

PLACEHOLDER—Work in Progress
Up level 4A & 4B to overarching challenges
Connect to simplified key set of combined key dates

Thrust 4A—Top 4 Risks

1. Supply and demand of alternative jet fuels as affected by the cost and the cost volatility of petroleum-based jet fuel. Currently low petroleum prices would imply that there may be less of a financial incentive to produce and to purchase alternative jet fuels however, public and policy pressure may continue to emphasize the life-cycle environmental benefits. Long-term fuel cost volatility may be reduced with availability and use of alternative jet fuels.
2. Alternative jet fuel compatible propulsion systems has been addressed by the FAA under their CLEEN initiative but long-term fuel effects may be more uncertain.
3. Alternative jet fuel storage and shelf life is a new area of unknown that is associated with long-term use of these fuels.
4. Unknown particulate matter (PM) regulations—It is expected that ICAO will formally address the topic of PM regulation following their initial decisions associated with a CO_2 standard. Industry and market response to impending regulations may affected R&D direction.

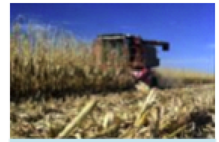
Thrust 4B—Top 4 Risks

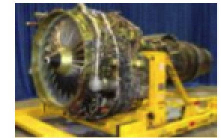
1. If industry does not agree significant benefits can be achieved then they will not invest in vehicles
2. If HEP component technologies are not realized, then the benefits of HEP vehicles will not be fully realized
3. If electrification poses significant safety or certification hurdles, then integration into fleet will become too costly
4. If energy sources used to power electric/hybrid electric systems are not from clean energy from a life cycle perspective, the climate benefits will not be realized nor systems developed and fielded.

Alternative Jet Fuel Development Path

Federal Partner Agency Contributions








	Feedstock Development & Production	Feedstock Logistics	Fuel Conversion / Fuel Conversion Scale-Up	Fuel Testing & Evaluation	Integrated Challenges
DOC	X				X
DoD			X	X	
DOE	X	X	X		X
DOT				X	X
EPA					X
NASA				X	
NSF	X	X	X		
USDA	X	X	X		X

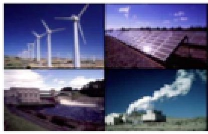
Diverse industry contributions along full development path

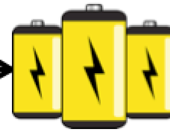
Academia contributions in low TRL and FRL*

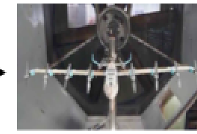
* Fuel Readiness Level

Hybrid Electric Aircraft

Interagency and Industry Contributions



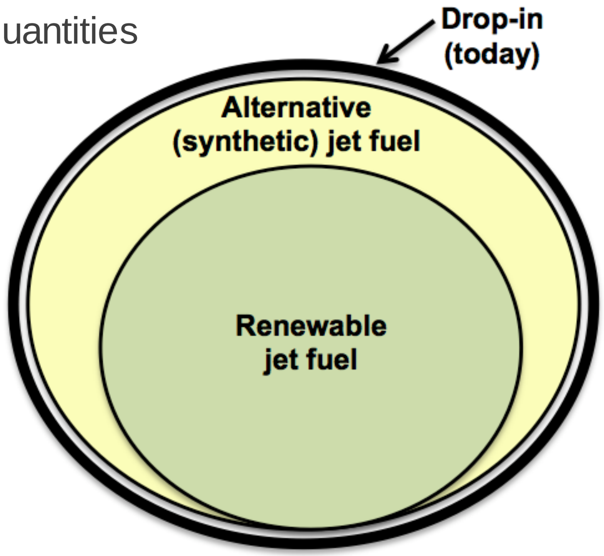





	Electrical Energy Production	Electric Distribution	Energy Storage	Integrated Designs	System Testing & Evaluation	Certification	End User/ Buyer
DoD				✓	✓		✓
DOE	✓	✓	✓				
FAA						✓	
NASA				✓	✓		
Engine Companies				✓	✓		
Airframers				✓	✓		
Operators							✓
Energy and Transport Industry	✓	✓	✓				

NASA

Thrust 4A Glossary



1. **Jet A** = petroleum-based kerosene jet fuel currently used in large quantities (aka **conventional jet fuel**)
2. **Alternative (or synthetic) jet fuel** = non-petroleum-based jet fuel produced from bio-feedstocks (plants, animal tallow, algae, etc.) or other non-petroleum feedstocks (e.g. municipal waste); these also include coal-to-liquid or mined" natural gas-to-liquid produced kerosene fuels as well.
3. **Renewable jet fuels** (or bio-jet fuel) = the subset of alternative jet fuels specifically produced from bi-feedstocks (renewable sources); these exclude fossil fuel-based fuels (coal-to-liquid or mined" natural gas-to-liquid produced kerosene fuels)
4. **Drop-in jet fuels** = the specific formulations of 2 and 3 above that have characteristics similar enough to petroleum-based jet fuels (kerosene) that the current fuels infrastructure and engine systems can be used. Presently, the FAA and ASTM standards (conservative) only allow for use up to a 50% blend of these alternative jet fuels with petroleum-based Jet A.
5. **Non-drop-in fuels** = fuels that are significantly different from current petroleum-based kerosene fuels that the currently available infrastructure and engine systems would not likely be sufficient. Such fuels might be considered in association with either Bryaton- or non-Brayton cycles. These fuels could include natural gas (either compressed or liquid) or hydrogen. May also be called "non-conventional fuels."
6. **Brayton cycle** = the specific operational cycle associated with gas turbine (jet) engines

* "mined" reflects that alternative fuels produced from natural gas derived from biological oxidation processes (e.g., waste products or sewage) would be renewable.

Timeline of Machine Power with Application to Aircraft Class